2019 REPORT ON EARTHQUAKE ACTIVITY IN OHIO

compiled by Jeff Fox, Daniel Blake, and Jacqueline Mills

OHIO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES

Graphic design & layout: Jeremy E. Gladden
Editing: Anthony J. Bresnen
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STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Michael P. Angle, Chief

Columbus 2021

PREFACE

The 2019 Report on Earthquake Activity in Ohio continues the efforts of the ODNR Division of Geological Survey to present a clear and concise representation of all seismicity, natural and human-made, in the state for the calendar year. This report presents the data in tables and figures, with brief discussions of significant earthquakes or seismic swarm activity. The computer program HYPOINVERSE-2000 (Klein, 2012) was used to process earthquake data in SEISAN and Earthworm. The earthquake listing in Table 3 is estimated to be systematically complete above magnitude M_L1.5 within the state for the 2019 calendar year. However, these data are preliminary—both the locations and magnitudes in this table are subject to revision. The catalog may include some human-made seismic events not yet identified.

The map of earthquake epicenters is continually updated and is available for viewing on the Ohio Earthquake Epicenters Locator interactive map, available here: **https://gis.ohiodnr.gov/MapViewer/?config=Earthquakes**. Seismic station lists and locations are current to the calendar year of this report only. Seismic station information can also be found on the interactive map. Station metadata is available from the IRIS Data Management Center. Station locations contained within this report are not accurate for privacy purposes. Interested scientists can obtain detailed location information for performing earthquake locations from the IRIS DMC.

A complete copy of this report, including maps and earthquake catalog, is available on the ODNR Earthquakes website at **ohioseis.ohiodnr.gov**.

Jeff Fox
Seismologist

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ABBREVIATIONS USED IN THIS REPORT

Units of Measure

kilometers . . . . . km
meters . . . . . m
miles . . . . . mi

Other

Advanced National Seismic System . . . . . ANSS
ANSS Quake Management System . . . . . AQMS
Incorporated Research Institutions for Seismology . . . . . IRIS
Magnitude . . . . . M_L
Ohio Seismic Network . . . . . OhioSeis
United States Geological Survey . . . . . USGS

EARTHQUAKE ACTIVITY IN OHIO
JANUARY 1–DECEMBER 31, 2019

During the period January 1 through December 31, 2019, the Ohio Seismic Network (seismic network code: OH) located 78 earthquakes within the Ohio region (table 1 and fig. 1). The total includes one earthquake of magnitude[1] 4.0 or greater and 18 earthquakes of magnitude 2.0 or greater. Earthquakes of magnitude 3.0 or larger are discussed later in this text. Nine earthquakes were reported felt in 2019. A cumulative tabulation of earthquakes during 2019 that were either felt in the Ohio region or for which a ShakeMap was produced, or both, is available in table 2. Additional information on earthquakes within the Ohio region is available from the Ohio Seismic Network online database.

[1]The original magnitude relationship was defined by Richter and Gutenberg in 1935 for local earthquakes based on the maximum amplitude of a seismogram recorded on a Wood-Anderson torsion seismograph. Although these instruments are no longer widely in use, M_L values are calculated using modern instrumentation with appropriate adjustments. Reported by USGS for all earthquakes in the U.S. and Canada. Only authoritative for smaller events, typically M<4.0 for which there is no Mb or moment (Mw) magnitude. In the central and eastern United States, USGS also computes M_L but restricts the distance range to 0–150 km.

TABLE 1. ***Earthquake magnitude statistics for calendar year 2019, all of Ohio***

2019 Ohio Earthquakes Summary	
Earthquakes (all magnitudes)	78
Earthquakes ≥ M4.0	1
Earthquakes M2.0–M3.9	18
Earthquakes ≤ M1.9	59
Earthquakes receiving Felt Reports	9

FIGURE 1. Earthquake epicenters located by the Ohio Seismic Network seismograph stations in 2019.

NOTABLE EARTHQUAKE EVENTS, JANUARY 1–DECEMBER 31, 2019

During the report period, there were four other notable spatial clusters of earthquake activity. For reporting purposes, we define a cluster as ten or more earthquakes occurring within a 10-kilmoter (km) (6-mile [mi]) radius. A cluster of 12 earthquakes (M_L 0.8–M_L 2.3) occurred approximately 8 mi southwest of Caldwell, Ohio. This cluster of events is actively being studied and occurred in an area with no previously recorded seismic activity. Another cluster of 22 earthquakes (M_L 0.7–M_L 2.6) occurred about 12 mi southeast of Caldwell. These earthquakes also occurred in an area previously devoid of recorded earthquake activity. Another cluster of 16 earthquakes (M_L 0.8–M_L 2.0) occurred about 4 mi northeast of Freeport, Ohio. Previous earthquake swarms in this area have been attributed to hydraulic fracturing operations (Skoumal and others, 2015). Finally, a cluster of 12 earthquakes (M_L 1.0 – M_L 1.9) occurred about 2 mi south of Marietta, Ohio. The cause of this seismic activity is unknown[2].

The locally clustered seismic events (fig. 1) within a radius of approximately 10 mi of Caldwell, in Noble County, and those within a radius of approximately 4 mi from Freeport in Harrison County, are located near areas of underground wastewater fluid injection and hydraulic fracturing. Previous earthquake activity in the same region are interpreted to be induced (Friberg and others, 2014).

Of notable importance concerning earthquake activity in Ohio during 2019 was the M_L 4.2 earthquake sequence under Lake Erie at 10:50 a.m. local time, June 10 (fig. 2). The earthquake was widely felt in Ohio and surrounding states, as well as into Ontario, Canada. The Ohio Seismic Network reported several earthquakes close to the mainshock epicenter prior to the mainshock, starting March 12 with the last one on May 20. Meanwhile, several aftershocks were recorded by nearby stations in the week following the mainshock. Another active burst of earthquakes occurred in December 2019 with the largest M_L 2.6 earthquake on December 7 (Yao and others, 2021).

[2] To view information for specific seismic events, please visit the online Ohio earthquake database at **ohiodnr.gov/earthquakedatabase**.

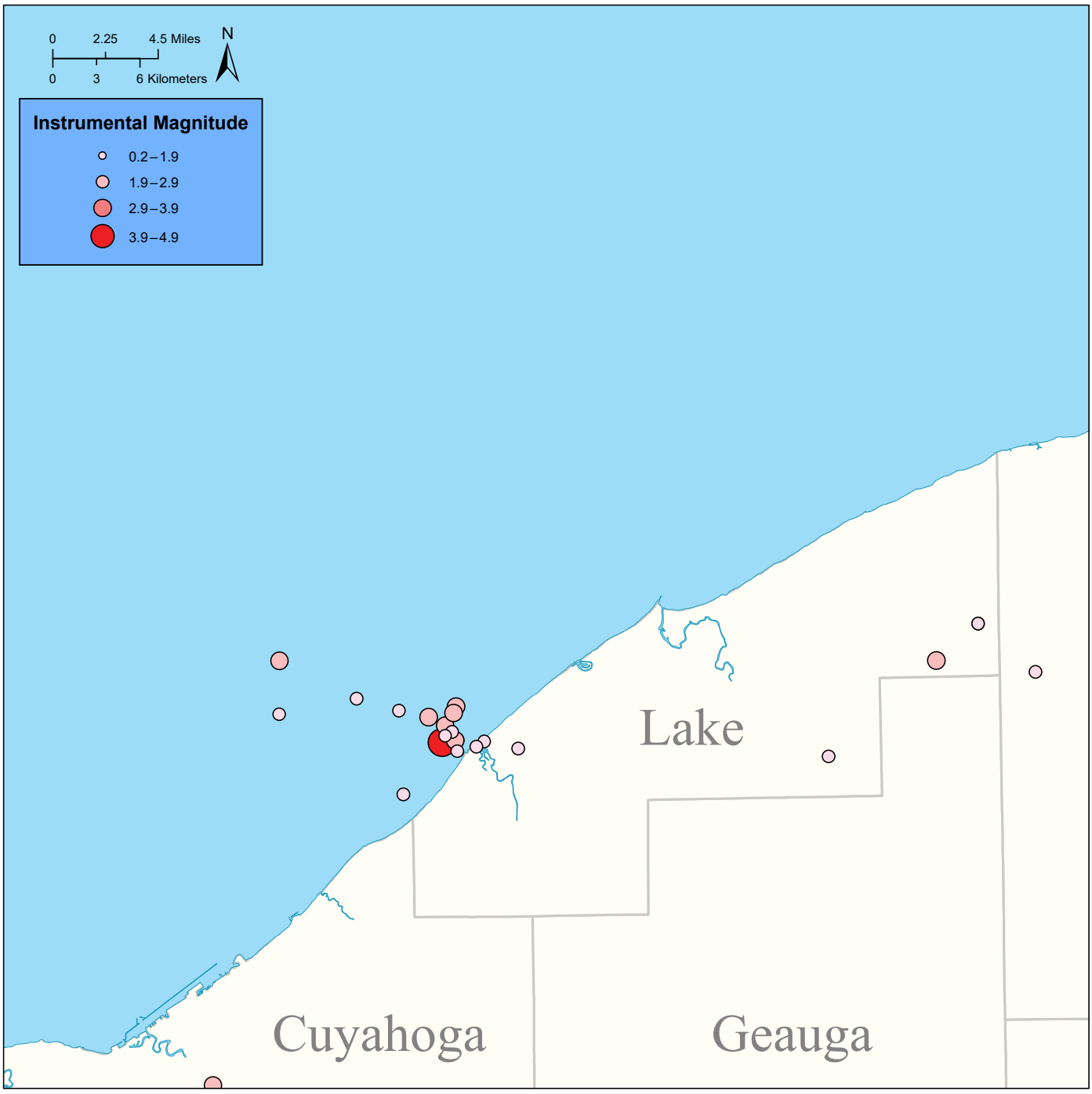


FIGURE 2. Detail map of the June 2019 Lake County earthquake sequence.

The relocated seismicity (fig. 2) reveals a linear feature trending approximately east–west. This feature aligns approximately 100 degrees from true north, given by St. Louis University, which might be indicative of the fault plane. The inferred fault dimension of ~5 km is larger than the characteristic dimension of a M_L 4.2 earthquake of ~1 km, inferring that this fault might be capable of hosting even larger earthquakes (Yao and others, 2021). Historically, the 1986 M_L 5.0 earthquake occurred 25 km east of the 2019 M_L 4.2 epicenter and was interpreted to have a fault orientation along a north–south direction. Another M_L 4+ earthquake geographically located between the 1986 and 2019 earthquakes occurred in 1943 (Hansen and Fox, 2020). Given the large offset between these mainshocks, as well as different fault orientations between the 1986 and 2019 events, seismologists are still unsure of how they potentially link to each other. Moreover, the distribution of seismicity might indicate complex faulting in this region. Because of sparse station distribution, additional smaller events could be hidden. A denser network with better azimuthal coverage would be required to monitor the local seismicity and obtain refined fault structures, which is crucial for seismic hazard estimation and mitigation in populated cities in the southern Great Lakes region.

FELT EARTHQUAKE EVENTS FOR 2019

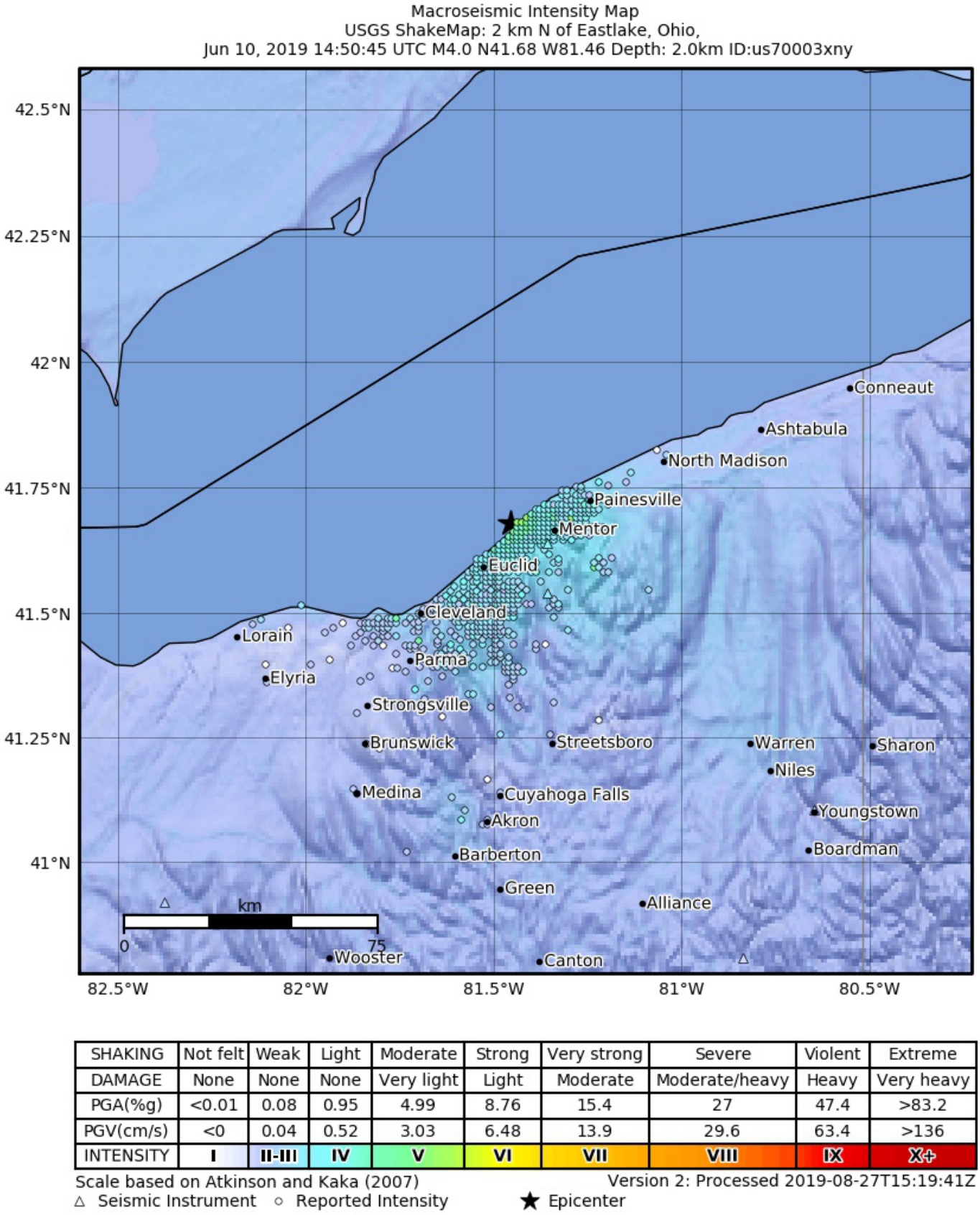
For earthquakes M_L 3.0 and larger in the Ohio region, the U.S. Geological Survey (USGS) automatically posts a Community Internet Intensity Map (CIIM) on its "Did You Feel It?" web page at **http://earthquake.usgs.gov/earthquakes/dyfi/**. We encourage anyone who feels an earthquake to report their observations on this interactive website. Felt information is available by zip code on the CIIM site or can be obtained from OhioSeis directly.

TABLE 2. ***Earthquakes felt and/or generating a Shakemap in the Ohio region, January 1–December 31, 2019***

DATE	TIME †	FELT INFORMATION	LATITUDE	LONGITUDE	MAGNITUDE (M_L)§
Mar 3	01:15 EST 06:15 UTC	USGS ShakeMap. CIIM. Felt (III) Greenfield, OH and (II) Fostoria, OH.	38.903 N	83.832 W	2.5
Mar 6	23:15 EST (Mar 5) 04:15 UTC	USGS ShakeMap. CIIM. Felt (II) Cleveland, OH.	41.459 N	81.653 W	2.0
Jun 10	10:50 DST 14:50 UTC	USGS ShakeMap. CIIM. Felt (V) at Eastlake, OH (IV) at Cleveland, OH and (III) Canton, OH.	41.678 N	81.437 W	4.2
Jun 15	16:06 DST 20:06 UTC	USGS ShakeMap. CIIM. Felt (II) Eastlake, OH and (II) Cleveland, OH.	41.689 N	81.478 W	1.8
Jun 17	22:28 DST (Jun 16) 02:28 UTC (Jun 17)	USGS ShakeMap. CIIM. Felt (III) Euclid, OH and (II) Wickliffe, OH.	41.666 N	81.488 W	1.6
Oct 15	01:25 DST 05:25 UTC	USGS ShakeMap. CIIM. Felt (III) Madison, OH and (II) Perry, OH.	41.728 N	81.052 W	2.6
Dec 7	15:06 UTC	USGS ShakeMap. CIIM. Felt (IV) Eastlake, OH.	41.648 N	81.472 W	2.6
Dec 10	17:25 UTC	USGS ShakeMap. CIIM. Felt (III) Mentor, OH.	41.683 N	81.482 W	1.7
Dec 12	21:23 UTC	USGS ShakeMap. CIIM. Felt (III) Willoughby, OH.	41.722 N	81.432 W	2.0

† Times are listed both as Local Time—Eastern Standard Time (EST) or Eastern Daylight Time (DST)—and as Universal Coordinated Time (UTC). CIIM is Community Internet Intensity Map (http://earthquake.usgs.gov/earthquakes/dyfi), compiled by the U.S. Geological Survey (USGS); ShakeMap indicates the availability of computer-generated maps of ground shaking (https://earthquake.usgs.gov/earthquakes/search/), produced by the OhioSeis Seismograph Stations (OH). Roman numerals correspond to the Modified Mercalli intensity scale. Unless otherwise indicated, felt information is from the USGS (1) CIIM reports and/or (2) PDE Monthly (or) Weekly Listing Files (http://earthquake.usgs.gov/data/pde.php).

§ Richter local magnitude (M_L) or coda magnitude (M_C) determined by OhioSeis.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.01	0.08	0.95	4.99	8.76	15.4	27	47.4	>83.2
PGV(cm/s)	<0	0.04	0.52	3.03	6.48	13.9	29.6	63.4	>136
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Atkinson and Kaka (2007) Version 2: Processed 2019-08-27T15:19:41Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

FIGURE 3. USGS ShakeMap from the June 10, 2019 M_L 4.2 Lake County, Ohio, earthquake. For definition of MMI Intensities, see glossary at the end of this report.

TABLE 3. ***Catalog of all earthquakes in Ohio in 2019***[1]

Year	Month	Day	Hour[2]	Minute	Second	Lat	Lon	Depth[3] (Km)	Mag
2019	1	6	11	4	1.3	39.427	-81.694	5.0	1.5
2019	1	13	8	1	28.4	41.666	-81.145	5.0	1.8
2019	1	20	19	26	6.6	39.111	-81.908	20.0	1.6
2019	1	26	12	11	29.8	38.475	-83.915	5.0	2.0
2019	2	23	18	32	52.7	40.227	-81.115	3.0	1.2
2019	3	3	1	34	36.0	38.468	-83.921	4.7	1.3
2019	3	3	6	15	45.1	38.913	-83.834	15.0	2.5
2019	3	6	4	15	3.7	41.467	-81.655	15.0	2.4
2019	3	8	2	12	0.0	40.225	-81.136	3.0	1.1
2019	3	11	18	20	13.2	40.185	-81.108	3.0	1.3
2019	3	20	21	57	7.9	38.886	-82.873	10.0	2.1
2019	3	12	4	11	29.0	40.215	-81.146	3.0	1.5
2019	3	12	8	17	31.0	40.208	-81.136	1.1	1.3
2019	3	19	23	15	55.0	40.234	-81.162	3.0	1.7
2019	3	24	15	34	53.9	40.214	-81.140	3.0	1.0
2019	4	3	20	48	55.2	41.772	-84.982	5.0	2.7
2019	4	8	0	39	13.3	40.266	-81.234	5.0	1.0
2019	4	8	0	40	40.3	40.230	-81.213	5.0	0.8
2019	4	8	0	52	37.7	40.231	-81.211	5.0	1.3
2019	5	20	21	12	49.6	41.684	-81.455	2.0	1.9
2019	6	10	14	50	45.5	41.678	-81.437	2.0	4.2
2019	6	10	14	54	41.1	41.696	-81.454	2.0	2.1
2019	6	10	14	57	35.0	41.672	-81.451	2.0	1.7
2019	6	10	15	4	30.0	41.688	-81.461	2.0	2.3
2019	6	10	15	43	47.0	41.678	-81.429	2.0	1.8
2019	6	10	15	47	42.3	41.700	-81.452	2.0	2.5
2019	6	10	16	22	13.0	41.675	-81.435	2.0	1.0
2019	6	10	17	56	41.0	41.730	-81.597	2.0	2.4
2019	6	10	19	39	16.0	41.694	-81.475	2.0	2.4
2019	6	15	20	6	42.0	41.706	-81.534	2.0	1.9
2019	6	17	2	28	56.0	41.674	-81.401	2.0	1.5
2019	6	10	15	14	43.0	41.697	-81.598	2.0	1.6
2019	8	23	7	34	30.1	39.088	-81.992	15.0	1.9

TABLE 3. ***Catalog of all earthquakes in Ohio in 2019[1] (continued)***

Year	Month	Day	Hour[2]	Minute	Second	Lat	Lon	Depth[3] (Km)	Mag
2019	9	9	21	3	56.8	39.355	-81.438	5.0	1.3
2019	9	9	21	4	5.6	39.354	-81.438	5.0	1.5
2019	9	9	21	6	9.0	39.365	-81.437	5.0	0.8
2019	9	9	21	30	46.1	39.360	-81.435	5.0	1.0
2019	9	9	21	30	14.4	39.377	-82.426	5.0	0.2
2019	9	11	6	37	21.2	40.225	-81.210	5.0	2.0
2019	9	11	8	21	0.2	40.224	-81.211	5.0	1.2
2019	9	11	10	3	55.8	40.224	-81.212	5.0	2.0
2019	9	11	10	4	7.5	40.225	-81.211	5.0	0.7
2019	9	24	18	56	35.1	39.632	-81.553	5.0	1.6
2019	9	24	21	35	50.8	39.632	-81.556	5.0	2.0
2019	9	25	2	46	20.7	39.637	-81.514	5.0	1.2
2019	9	25	2	19	3.2	39.636	-81.551	5.0	1.7
2019	9	25	0	37	45.7	39.645	-81.558	5.0	0.5
2019	9	24	18	30	30.6	39.643	-81.575	5.0	0.9
2019	9	9	21	5	9.8	39.365	-81.436	5.0	1.5
2019	9	9	21	45	37.8	39.354	-81.441	5.0	0.8
2019	9	9	21	3	36.3	39.364	-81.433	5.0	0.7
2019	9	9	21	3	45.8	39.363	-81.434	5.0	0.7
2019	9	9	21	3	53.3	39.353	-81.440	5.0	0.8
2019	10	7	2	22	58.2	41.717	-80.973	5.0	1.5
2019	10	21	0	34	54.2	39.633	-81.573	5.0	2.3
2019	10	20	10	14	30.8	40.716	-84.154	15.0	1.3
2019	10	24	7	32	15.0	38.560	-83.654	5.7	1.8
2019	10	29	20	5	20.4	39.647	-81.289	5.0	1.2
2019	10	15	5	25	9.3	41.725	-81.056	5.0	2.7
2019	10	31	4	59	2.4	39.673	-81.344	5.0	1.6
2019	11	8	2	44	8.8	39.673	-81.345	5.0	1.5
2019	11	9	9	10	47.6	39.666	-81.346	5.0	1.6
2019	11	8	23	19	58.3	39.665	-81.331	5.0	1.9
2019	11	5	5	27	31.5	39.671	-81.326	5.0	1.5
2019	11	3	4	6	7.0	39.657	-81.320	5.0	1.9
2019	11	3	3	17	49.4	39.666	-81.324	5.0	1.8

TABLE 3. ***Catalog of all earthquakes in Ohio in 2019[1] (continued)***

Year	Month	Day	Hour[2]	Minute	Second	Lat	Lon	Depth[3] (Km)	Mag
2019	11	2	10	6	19.9	39.667	-81.319	5.0	1.8
2019	11	4	4	36	27.4	39.664	-81.328	5.0	1.2
2019	11	4	20	39	30.1	39.663	-81.329	5.0	1.6
2019	11	7	23	49	43.3	39.657	-81.320	5.0	2.1
2019	12	7	15	6	19.2	41.679	-81.453	2.0	2.6
2019	12	7	5	26	52.9	41.747	-81.020	2.0	1.7
2019	12	10	17	25	44.0	41.646	-81.496	6.0	1.7
2019	12	7	5	26	52.9	41.747	-81.020	2.0	1.7
2019	12	6	15	6	19.2	41.679	-81.453	2.0	2.6
2019	12	10	17	25	43.9	41.682	-81.461	2.0	1.3
2019	12	11	21	23	28.0	41.698	-81.499	2.0	1.7
2019	12	31	2	21	2.0	38.385	-83.264	16.0	1.9

[1]Earthquakes listed in chronological order. All magnitudes are M_L unless denoted otherwise.
[2]UTC: Universal Time Coordinated. All earthquake origin times are given in UTC time by hour. UTC is similar to GMT (Greenwich Mean Time). To convert to local time, subtract 5 hours for Eastern Standard Time (EST) and 4 hours for Daylight Saving Time (DST).
[3]Earthquake depth listed in km below datum.

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- Dr. Won-Young Kim, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York
- Ohio Department of natural Resources, Division of Oil & Gas Resources Management
- U.S. Geological Survey
- Incorporated Research Institutions for Seismology

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APPENDIX

Seismic Network Discussion

Hardware

The Ohio Seismic Network has operated a network comprised of remote, solar powered seismic stations since early 2016. At the time of this report, OhioSeis is comprised of 19 operating seismic stations throughout the state (fig. A-1). Stations are built primarily of an aluminum box which contains a voltage regulation system, a 12V battery bank, a cellular modem for data transfer and in some instances, a seismic digitizer. The box is affixed to a pole which supports two 90 Watt solar panels that charge the batteries. The seismometer is housed in a below-ground vault and is cemented in place and insulated from daily temperature swings and atmospheric effects (fig. A-1). The network also consists of three stations previously owned, installed, and operated by the Incorporated Research Institutes for Seismology (IRIS), which contain all equipment, power, voltage regulation and cellular below ground, except for the solar panels (fig. A-2).

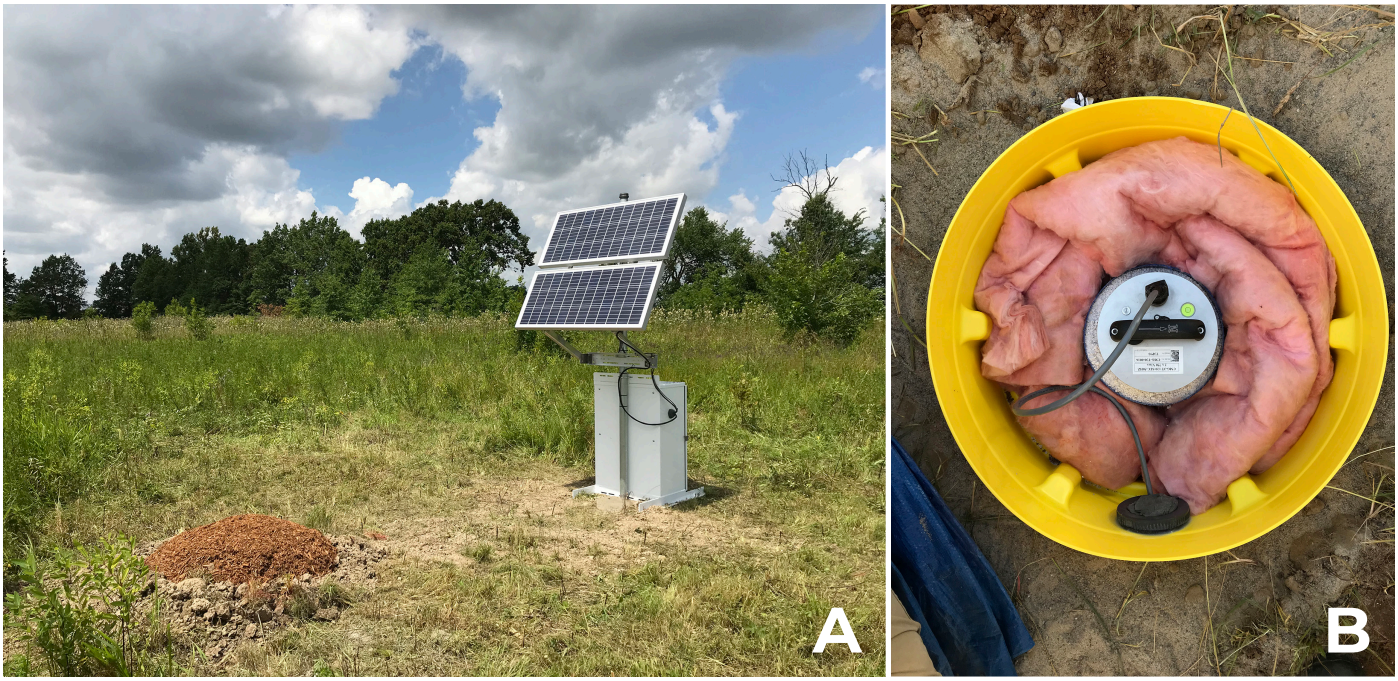

FIGURE A-1. A (left): Typical design and layout of OhioSeis seismic station power module. Seismometer is buried nearby under earthen mound. B (right): Seismometer as it appears insulated inside buried vault drum.

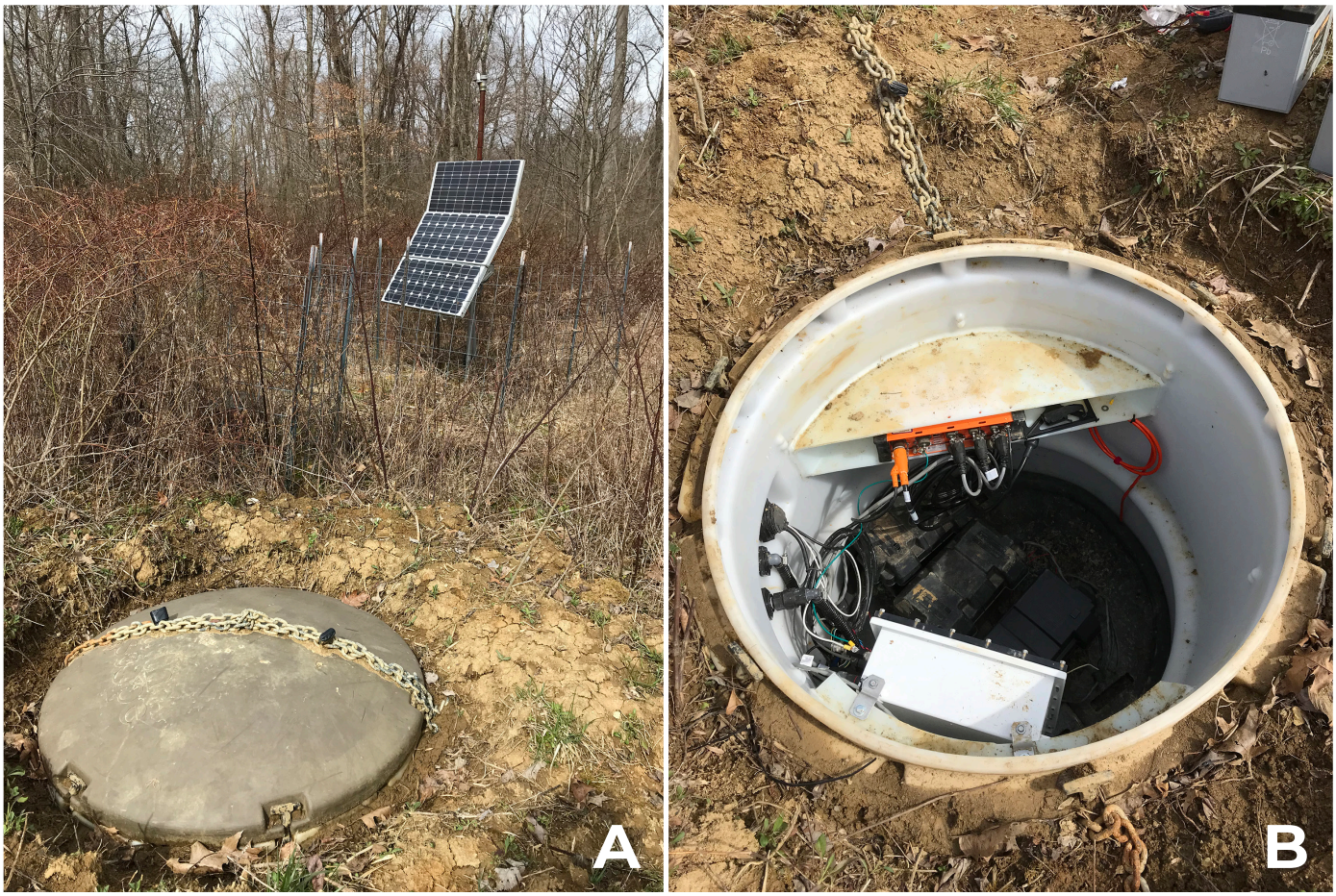

FIGURE A-2. A (left): Typical design and layout of former IRIS stations adopted by OhioSeis. B (right): IRIS seismic digitizer and communications equipment as it appears inside buried vault drum.

Software

The Ohio Seismic Network added powerful new data analysis capabilities in 2019. Since 2015, the Ohio Seismic Network has been using the Earthworm Seismic Data Management and alert notification software. This software package records, archives, and forwards data to the IRIS Data Management Center as well as detects all seismic activity from field based seismic stations throughout Ohio that are fed into it. This attribute allows OhioSeis staff to be alerted to seismic events in real-time.

In 2019, OhioSeis upgraded to Earthworm version 7.10 and moved the system from a local PC to a production Linux server at the State of Ohio Computer Center. OhioSeis staff also began experimenting with additional detection modules that are tuned for specific seismic zones within the state in order to better detect smaller seismic events.

To complement the Earthworm data system, OhioSeis integrated the AQMS (ANSS Quake Management System) software package. The project was completed in December 2019. The software serves as both an earthquake database and post-processing suite. AQMS includes a program called Jiggle that allows OhioSeis staff to determine the location, depth, magnitude, and other important statistics. AQMS is an all-in-one solution that replaces numerous open-source programs previously used by OhioSeis.

AQMS uses a new version of the computer program HYPOINVERSE-2000 (Klein, 2012) and a revised and expanded set of velocity models, which are critical for earthquake location determination. The primary effect of HYPOINVERSE-2000 and the customized velocity models results in more precise earthquake locations. The program accounts for station elevation differences more accurately and reports focal depths relative to sea level instead of the 250 m elevation datum used previously.

TABLE A-1. ***Ohio Seismic Network operating seismograph stations as of December 31, 2019***

STATION NAME		County	Installed	SENSOR	DIGITIZER	MODEM
BCOH	Blue Creek Metro Park	Lucas	2019	GURALP CMG-6TD	Onboard	RV50
BGOH	Bowling Green University- Firelands	Erie	2019	GURALP CMG-6TD	Onboard	RV50
BSPO	Barkcamp State Park	Belmont	2018	GURALP CMG-6TD	Onboard	RV50
CHWO	Cooper Hollow State Nature Preserve	Jackson	2018	GURALP CMG-6TD	Onboard	RV50
CPOH	Chaparral Prairie State Nature Preserve	Adams	2019	GURALP CMG-3T	Reftek RT 130	RV50
KDOH	Killdeer Plains Wildlife Area	Wyandot	2019	SERCEL L22 3D	Reftek RT 130	RV50
KLOH*	Kiser Lake State Park	Champaign	2019	GURALP CMG-6TD	Onboard	RV50
LEBO	Lake Erie Bluffs Metro Park	Lake	2016	GURALP CMG-6TD	Onboard	RV50
M53A	Farmdale, OH	Trumbull	2018	NANOMETRICS Trillium 240	Q330	RV50
MFOH	Malabar Farms State Park	Richland	2019	GURALP CMG-3T	Reftek RT 130	RV50
MWLO	Mercer Wildlife Area	Mercer	2018	GURALP CMG-6TD	Onboard	RV50
O53A	Freeport, OH	Harrison	2018	STRECKEISEN STS-2	Q330	RV50
P51A	Williamsport, OH	Ross	2018	NANOMETRICS Trillium 240	Q330	RV50
P52A	Corning, OH	Perry	2018	STRECKEISEN STS-2	Q330	RV50
SLSO	Stonelick State Park	Clermont	2018	GURALP CMG-6TD	Onboard	RV50
SROH	Shade River State Forest	Meigs	2019	GURALP CMG-3T	Reftek RT 130	RV50
SSFO	Shawnee State Forest	Scioto	2016	GURALP CMG-6TD	Onboard	RV50
SSPO	Sycamore State Park	Montgomery	2019	GURALP CMG-6TD	Onboard	RV50
VLOH	Vernon Luthman Wildlife Area	Shelby	2019	SERCEL L22 3D	Reftek RT 130	RV50
* KLSO was relocated and renamed to KLOH on July 10, 2019.						

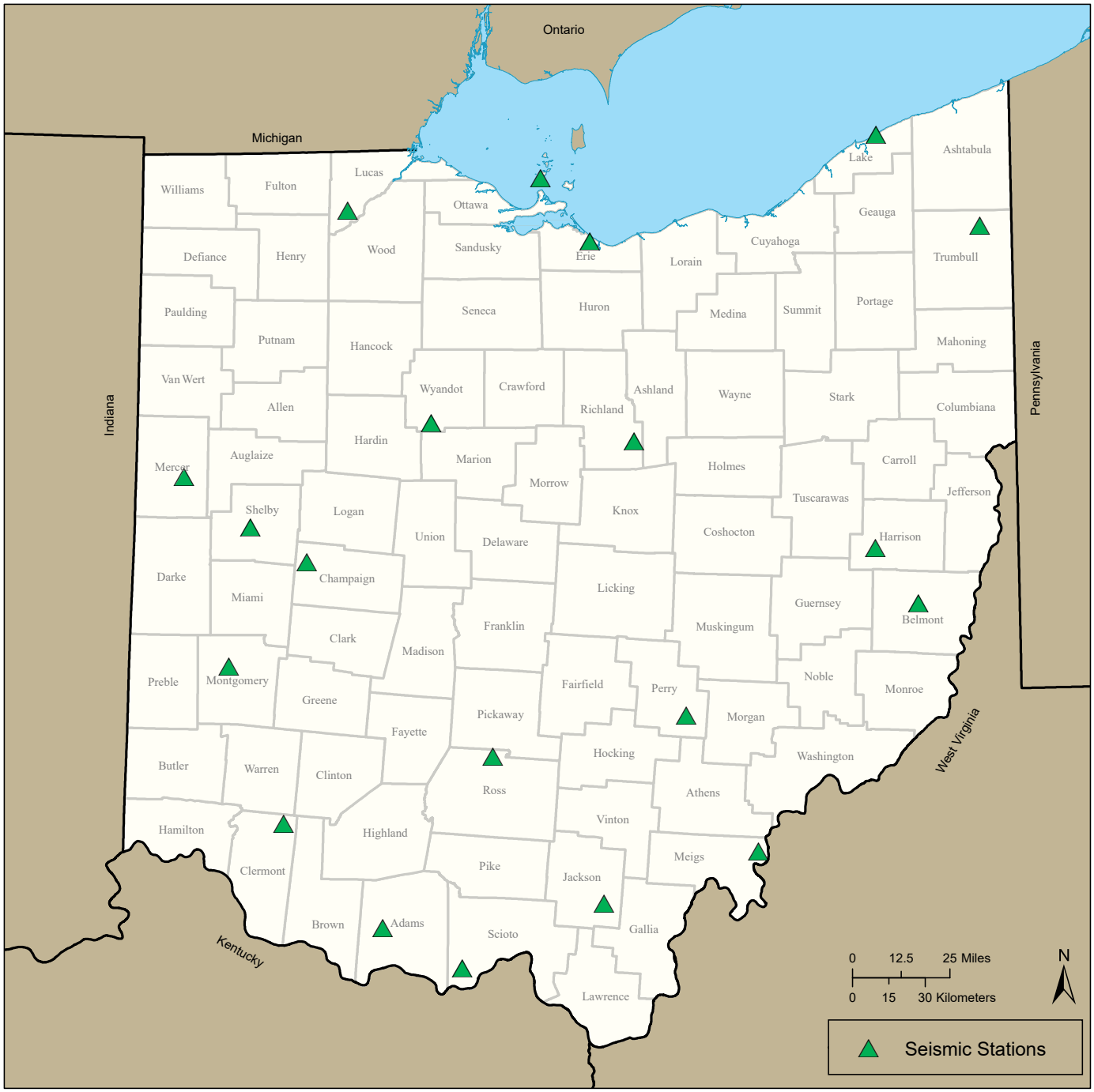

FIGURE A-3. Ohio Seismic Network station locations map for 2019.

CIIM Intensity	People's Reaction	Furnishings	Built Environment	Natural Environment
I	Not felt			Changes in level and clarity of well water are occasionally associated with great earthquakes at distances beyond which the earthquakes felt by people.
II	Felt by a few.	Delicately suspended objects may swing.		
III	Felt by several; vibration like passing of truck.	Hanging objects may swing appreciably.		
IV	Felt by many; sensation like heavy body striking building.	Dishes rattle.	Walls creak; window rattle.	
V	Felt by nearly all; frightens a few.	Pictures swing out of place; small objects move; a few objects fall from shelves within the community.	A few instances of cracked plaster and cracked windows with the community.	Trees and bushes shaken noticeably.
VI	Frightens many; people move unsteadily.	Many objects fall from shelves.	A few instances of fallen plaster, broken windows, and damaged chimneys within the community.	Some fall of tree limbs and tops, isolated rockfalls and landslides, and isolated liquefaction.
VII	Frightens most; some lose balance.	Heavy furniture overturned.	Damage negligible in buildings of good design and construction, but considerable in some poorly built or badly designed structures; weak chimneys broken at roof line, fall of unbraced parapets.	Tree damage, rockfalls, landslides, and liquefaction are more severe and widespread wiht increasing intensity.
VIII	Many find it difficult to stand.	Very heavy furniture moves conspicuously.	Damage slight in buildings designed to be earthquake resistant, but severe in some poorly built structures. Widespread fall of chimneys and monuments.	
IX	Some forcibly thrown to the ground.		Damage considerable in some buildings designed to be earthquake resistant; buildings shift off foundations if not bolted to them.	
X			Most ordinary masonry structures collapse; damage moderate to severe in many buildings designed to be earthquake resistant.	

FIGURE A-4. The Modified Mercalli Intensity Scale for earthquake shaking, courtesy of the USGS.

OHIO GEOLOGICAL SURVEY

DEPARTMENT OF NATURAL RESOURCES

(614) 265-6576 • geo.survey@dnr.ohio.gov

geology.ohiodnr.gov